

DEVELOPING OMEGA-3 FATTY ACIDS-ENRICHED ANIMAL PRODUCTS BY FEEDING DEFATTED MICROALGAL BIOMASS FROM BIOFUEL PRODUCTION

S.K. Gatrell, M.L. Manor and X.G. Lei
Department of Animal Science
Cornell University

INTRODUCTION

An increase in the public's demand for health value-added food products has prompted experiments to fortify functional nutrients into commonly consumed animal products such as eggs and chicken (Sim and Qi, 1995; Surai and Sparks, 2001; Perić et al., 2011; Fraeye et al., 2012). Currently, the average American consumes over 40 kg of broiler chicken and 250 eggs annually (USDA Economic Research Service, 2006), making these products excellent candidates for the desired enrichments. While chicken meat and eggs provide abundant essential amino acids and other key nutrients, they are relatively high in omega-6 (n-6) fatty acids and low in omega-3 (n-3) fatty acids. The opposing physiological effects of n-6 and n-3 fatty acids render these nutrients to be referred to as potentially pro-inflammatory and anti-inflammatory, respectively (Schmitz and Ecker, 2008). For this reason, the ratio of n-6 to n-3 fatty acids in foods is considered an important factor for human health (Simopoulos, 2008).

Current n-3 fatty acid-enriched animal products

The n-3 fatty acids are a group of polyunsaturated fatty acids that include α -linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). Improved intakes of n-3 fatty acids have been linked to reducing risks and prevalence of chronic diseases including diabetes, cardiovascular disease, arthritis and cancer (Daviglus et al., 1997; Albert et al., 1998; Ruggiero et al., 2009; Sala-Vila and Calder, 2011; Delgado-Lista et al., 2012). Recently, attempts at increasing the n-3 fatty acid content of animal products via feeding plant-based flaxseed (Jiang et al., 1991; Jia et al., 2008; Najib and Al-Yousef, 2011; Kartikasari et al., 2012; Anjum et al., 2013) or canola oil (Gallardo et al., 2012) have yielded moderate success. However, those increases are due to a large deposition of ALA, but not the longer-chain DHA or EPA. Because the conversion of ALA to EPA, and then to DHA *in vivo* is extremely low, animal products with enriched n-3 fatty acids from those plant-based ingredients have limited health value. Meanwhile, dietary inclusion of DHA and EPA-rich fish oil or fishmeal has been investigated as a means of enriching the desirable n-3 fatty acid in broiler chicken (Edwards and May, 1965; Hulan et al., 1988; Lopez-Ferrer et al., 2001) and eggs (Leskanich and Noble, 1997). However, EPA and DHA contain a greater number of double bonds and are more susceptible to oxidative breakdown than ALA, ultimately leading to an unacceptable flavor in the animal products (Fraeye et al., 2012).

Nutritional roles for defatted microalgal biomass

Global population is expected to grow by almost 30% to 9 billion by the year 2050 (Secretariat, 2006), which leads to greater food demands. (Bruinsma, 2003; Secretariat, 2006). As animal products contribute approximately 30% and 40% of the calorie and protein intake, respectively, worldwide, a substantial expansion of the current animal production system will be needed to meet increasing food demands. However, one of the major constraints for the expansion of animal production is the shortage of feed protein supplements.

One potential alternative feed protein supplement is marine microalgae, due to their excellent nutritional composition. Crude protein contents in microalgae range from 6-71% of dry matter, depending on species and culture conditions (Becker, 2007). The microalgal biomass contains measureable amounts of essential amino acids (Gatrell et al., 2014a) that compare favorably with conventional ingredients such as corn and soybean meal. Marine microalgae also have a superior fatty acid profile compared to other feed protein sources, particularly a greater abundance of EPA and DHA (Fredriksson et al., 2006; Kalogeropoulos et al., 2010). Microalgae also contain naturally occurring carotenoids, including β -carotene and astaxanthin (Spolaore et al., 2006), which may help stabilize the n-3 fatty acids in the feeds and animal products (Barclay et al., 1994)

Health value of defatted microalgae for enriching n-3 fatty acids in animal products

As mentioned above, current n-3 fatty acid-fortified eggs and meats are produced by dietary inclusion of flaxseed, canola oil, fish oil, or fishmeal. In comparison with the inherent limitations of these ingredients, supplementation of marine microalgae may be advantageous due to their high levels of EPA and DHA as well as free-radical scavenging carotenoids. Initial results have shown promise with microalgae supplementation in poultry diets. Laying hens fed various species of microalgae all produced eggs with increased levels of n-3 fatty acids, specifically EPA and DHA (Abril et al., 1999; Fredriksson et al., 2006). Similarly, breast muscle from broiler chicks fed marine microalgae had increased n-3 content and an improved n-6 to n-3 fatty acid ratio (Mooney et al., 1998).

Our laboratory has conducted a series of experiments to assess the feasibility of creating n-3 fatty acid enriched eggs and chicken using various types of defatted marine microalgal biomass. We have demonstrated a linear increase of EPA and DHA in breast, thigh muscle, liver, and plasma of broiler chicks fed a defatted green microalgal biomass (Gatrell et al., 2014b). We have also shown that the defatted microalgal biomass alleviated negative effects of a high flaxseed oil inclusion on the health of laying hens, along with improvement in the egg yolk EPA content (Kim et al., 2014). Ongoing research is revealing impacts of the resultant enrichments of EPA and DHA on the storage stability, palatability, and health values of the animal products.

SUMMARY

Our past studies have proven that the defatted marine microalgal biomass from biofuel production research is an excellent alternative of soybean meal as a feed protein supplement. We have conducted a new series of experiments to illustrate that the same biomass, due to a high content of long chain n-3 fatty acids, may provide a unique opportunity to produce a healthier, value-added animal product.

ACKNOWLEDGEMENTS

This research was supported by USDA/DOE Biomass R&D Initiative and Cornell Hatch grants.

REFERENCES

- Abril, J. R., W. R. Barclay, and P. G. Abril. 1999. Safe use of Microalgae (DHA GOLD) in Laying Hen Feed for the Production of DHA-Enriched Eggs. Pages 197-202
- Albert, C. M., C. H. Hennekens, C. J. O'Donnell, U. A. Ajani, V. J. Carey, W. C. Willett et al. 1998. Fish consumption and risk of sudden cardiac death. *JAMA*. 279(1): 23-28.
- Anjum, F. M., M. F. Haider, M. I. Khan, M. Sohaib, and M. S. Arshad. 2013. Impact of extruded flaxseed meal supplemented diet on growth performance, oxidative stability and quality of broiler meat and meat products. *Lipids Health. Dis.* 12: 13-511X-12-13.
- Barclay, W., K. Meager, and J. Abril. 1994. Heterotrophic production of long chain omega-3 fatty acids utilizing algae and algae-like microorganisms. *J. Appl. Phycol.* 6(2): 123-129.
- Becker, E. W. 2007. Micro-algae as a source of protein. *Biotechnol. Adv.* 25(2): 207-210.
- Bruinsma, J. 2003. World agriculture: Towards 2015/2030; an FAO perspective. Earthscan.
- Daviglus, M. L., J. Stamler, A. J. Orenchia, A. R. Dyer, K. Liu, P. Greenland et al. 1997. Fish consumption and the 30-year risk of fatal myocardial infarction. *N. Engl. J. Med.* 336(15): 1046-1053.
- Delgado-Lista, J., P. Perez-Martinez, J. Lopez-Miranda, and F. Perez-Jimenez. 2012. Long chain omega-3 fatty acids and cardiovascular disease: A systematic review. *Br. J. Nutr.* 107 Suppl 2: S201-13.
- Edwards, H. M., Jr, and K. N. May. 1965. Studies with menhaden oil in practical-type broiler rations. *Poult. Sci.* 44: 685-689.
- Fraeye, I., C. Bruneel, C. Lemahieu, J. Buyse, K. Muylaert, and I. Foubert. 2012. Dietary enrichment of eggs with omega-3 fatty acids: A review. *Food Res. Int.* 48(2): 961-969.
- Fredriksson, S., K. Elwinger, and J. Pickova. 2006. Fatty acid and carotenoid composition of egg yolk as an effect of microalgae addition to feed formula for laying hens. *Food Chem.* 99(3): 530-537.
- Gallardo, M. A., D. D. Perez, and F. M. Leighton. 2012. Modification of fatty acid composition in broiler chickens fed canola oil. *Biol. Res.* 45(2): 149-161.

- Gatrell, S., K. Lum, J. Kim, and X. G. Lei. 2014a. Nonruminant nutrition symposium: Potential of defatted microalgae from the biofuel industry as an ingredient to replace corn and soybean meal in swine and poultry diets. *J. Anim. Sci.* 92(4): 1306-1314.
- Gatrell, S. K., J. Kim, T. J. Derksen, E. V. O'Neil, and X. G. Lei. 2014b. Dose-dependent effect of a defatted green microalgal biomass on enriching omega-3 fatty acids in broiler chicken. *Journal of Animal Science*. 92(E-Suppl. 2): 233.
- Hulan, H., F. Proudfoot, R. Ackman, and W. Ratnayake. 1988. Omega-3 fatty acid levels and performance of broiler chickens fed redfish meal or redfish oil. *Canadian Journal of Animal Science*. 68(2): 533-547.
- Jia, W., B. A. Slominski, W. Guenter, A. Humphreys, and O. Jones. 2008. The effect of enzyme supplementation on egg production parameters and omega-3 fatty acid deposition in laying hens fed flaxseed and canola seed. *Poult. Sci.* 87(10): 2005-2014.
- Jiang, Z. R., D. U. Ahn, and J. S. Sim. 1991. Effects of feeding flax and two types of sunflower seeds on fatty acid compositions of yolk lipid classes. *Poult. Sci.* 70(12): 2467-2475.
- Kalogeropoulos, N., A. Chiou, E. Gavala, M. Christea, and N. K. Andrikopoulos. 2010. Nutritional evaluation and bioactive microconstituents (carotenoids, tocopherols, sterols and squalene) of raw and roasted chicken fed on DHA-rich microalgae. *Food Res. Int.* 43(8): 2006-2013.
- Kartikasari, L. R., R. J. Hughes, M. S. Geier, M. Makrides, and R. A. Gibson. 2012. Dietary alpha-linolenic acid enhances omega-3 long chain polyunsaturated fatty acid levels in chicken tissues. *Prostaglandins Leukot. Essent. Fatty Acids*. 87(4-5): 103-109.
- Kim, J., A. Magnuson, & X. G. Lei. 2014. Effects of three types of dietary microalgal inclusions on n-3 and n-6 fatty acid profiles in egg yolks of laying hens. *Journal of Animal Science*. 92(E-Suppl. 2): 233. (Abstr.)
- Leskanich, C. O., and R. C. Noble. 1997. Manipulation of the n-3 polyunsaturated fatty acid composition of avian eggs and meat. *Worlds Poult. Sci. J.* 53(02): 155.
- Lopez-Ferrer, S., M. D. Baucells, A. C. Barroeta, and M. A. Grashorn. 2001. N-3 enrichment of chicken meat. 1. use of very long-chain fatty acids in chicken diets and their influence on meat quality: Fish oil. *Poult. Sci.* 80(6): 741-752.
- Mooney, J. W., E. M. Hirschler, A. K. Kennedy, A. R. Sams, and M. E. Van Elswyk. 1998. Lipid and flavour quality of stored breast meat from broilers fed marine algae. *J. Sci. Food Agric.* 78(1): 134-140.
- Najib, H., and Y. M. Al-Yousef. 2011. Performance and essential fatty acids content of dark meat as affected by supplementing the broiler diet with different levels of flaxseeds. *Annual Review & Research in Biology*. 1(2): 22-32.
- Perić, L., V. Rodić, and N. Milošević. 2011. Production of poultry meat and eggs as functional food: Challenges and opportunities. *Biotechnology in Animal Husbandry*. 27(3): 511-520.
- Ruggiero, C., F. Lattanzio, F. Lauretani, B. Gasperini, C. Andres-Lacueva, and A. Cherubini. 2009. Omega-3 polyunsaturated fatty acids and immune-mediated diseases: Inflammatory bowel disease and rheumatoid arthritis. *Curr. Pharm. Des.* 15(36): 4135-4148.

- Sala-Vila, A., and P. C. Calder. 2011. Update on the relationship of fish intake with prostate, breast, and colorectal cancers. *Crit. Rev. Food Sci. Nutr.* 51(9): 855-871.
- Schmitz, G., and J. Ecker. 2008. The opposing effects of $n-3$ and $n-6$ fatty acids. *Prog. Lipid Res.* 47(2): 147-155.
- Secretariat, U. 2006. World population prospects: The 2006 revision. New York.
- Sim, J. S., and G. - Q. 1995. Designing Poultry Products using Flaxseed. Pages 315-333 American Oil Chemists' Society Press,
- Simopoulos, A. P. 2008. The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. *Exp. Biol. Med.* (Maywood). 233(6): 674-688.
- Spolaore, P., C. Joannis-Cassan, E. Duran, and A. Isambert. 2006. Commercial applications of microalgae. *J. Biosci. Bioeng.* 101(2): 87-96.
- Surai, P. F., and N. H. C. Sparks. 2001. Designer eggs: From improvement of egg composition to functional food. *Trends Food Sci. Technol.* 12(1): 7-16.
- USDA Economic Research Service. 2006. Poultry yearbook, young chicken: Per capita consumption, retail weight basis.